Vol. A57 (1980) ACTA PHYSICA POLONICA No 5

THE INFLUENCE OF Ar ON ELECTRICAL AND MAGNETIC PROPERTIES IN AMORPHOUS THIN FILMS $(Gd_{1-x}Co_x)_{1-y}Ar_y$*

By T. Groń** and T. Stobiecki

Solid State Physics Department, Metallurgy Institute, Academy of Mining and Metallurgy, Cracow***

(*Received September 3, 1979*)

The temperature dependence of coercivity, H_c, magnetisation, M_s, resistivity, ϱ, Hall resistivity, ϱ_H and the ratio, $|\varrho_H|/\varrho$, were studied. Measurements were done using amorphous magnetic thin films $(Gd_{1-x}Co_x)_{1-y}Ar_y$ for various Ar concentrations while the cobalt concentration was kept constant. It was found that the Ar presence influences many of the electrical and magnetic properties of the films.

1. Sample preparation

Amorphous Gd-Co films were prepared by D. C. sputtering in an Ar atmosphere using a cobalt target with gadolinium pieces [1]. Because of this technology Ar impurities are always present in the films. Samples were deposited on a glass substrate with a negative bias polarisation voltage applied which varied from 150 to 220 V. Different bias voltages made it possible to obtain perpendicular anisotropy and cylindrical domain structures [1, 2]. The thickness of the samples was determined by standard optical interference and this varied from 0.4 to 1.2 μm. The amorphous state of the film was confirmed by electron diffraction. The amount of Gd, Co and Ar was determined by a microprobe analyser.

2. Experiment

The coercivity, H_c, compensation temperature T_{comp} and the Hall resistivity of ϱ_H were obtained from Hall measurements. The D. C. method was used to measure the extraordinary Hall effect [3]. Samples were mounted in liquid nitrogen cryostat and the temperature was controlled from approximately 120 K to 460 K. The magnetisation of M_s was obtained from Faraday balance measurements.

* This work was partially supported by the Institute of Physics, Polish Academy of Sciences.

** Address: Zakład Fizyki Magnetyków, Instytut Fizyki, Uniwersytet Śląski, Uniwersytecka 4, 40-007 Katowice, Poland.

*** Address: Zakład Fizyki Ciała Stałego, Instytut Metalurgii, Akademia Górniczo-Hutnicza, Mickiewicza 30, 30-059 Kraków, Poland.

3. *Magnetic properties*

Typical Hall loops are shown in Fig. 1. The coercivity H_c is very temperature dependent. This also depends on the technological conditions and H_c may differ largely with different samples. We assume that this is due to Ar impurities and compositional fluctuations. We found that H_c increases with an increasing Ar concentration as shown

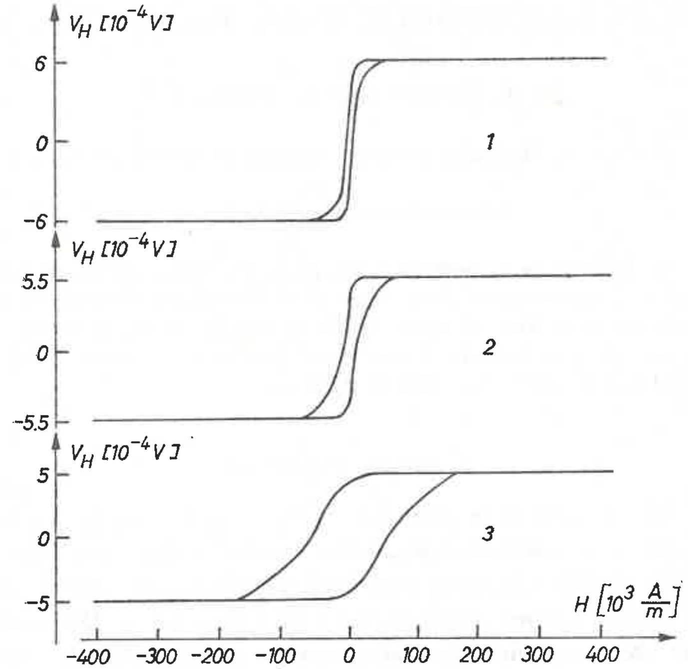

Fig. 1. Typical anomalous hysteresis loops of the Hall effect for $\Delta T = 64$ K where $\Delta T = T - T_{comp}$

in Fig. 1, 2 [4]. We believe that the H_c dependence on Ar concentration can be explained in terms of changes in the magnetisation. The saturation of magnetisation of the Gd-Co alloy decreases with an increase in Ar percentage (Fig. 3). This is due to larger inter-atomic distances between magnetic atoms which result in a decrease in the exchange integral, J_{Co-Gd}, with an increase in Ar concentration [5, 6].

This leads to a reduction in the average number of magnetic neighbours. Thus, the number of Gd atoms contributing to the magnetic interaction is reduced and this causes a decrease in the Co–Gd exchange integral, J_{Co-Gd} [5, 6]. This also supports the experimental evidence from Gangulee and Kobilska [6]. From Fig. 4 it can be seen that the coercivity, H_c, is inversely proportional to the magnetisation thus yields the observed H_c dependence on the Ar concentration.

The decrease in the Co-Gd exchange integral caused by an increase in Ar concentration also lowers the compensation temperature T_{comp} (Fig. 5, Table I) [7, 8].

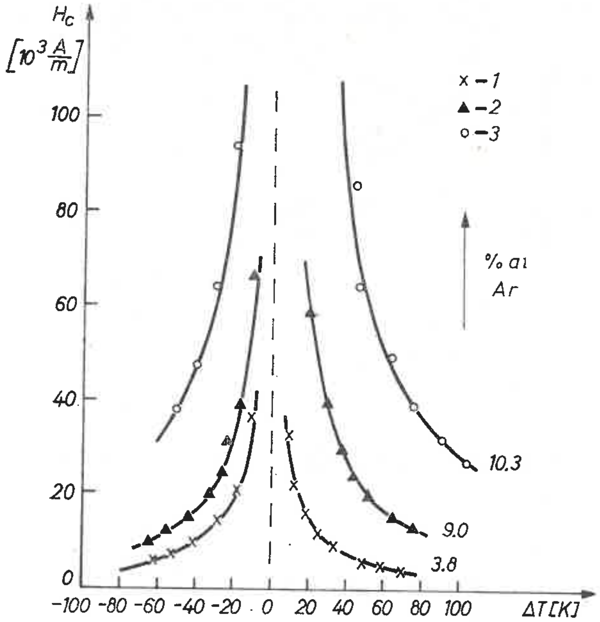

Fig. 2. Coercivity, H_c, vs ΔT where $\Delta T = T - T_{comp}$

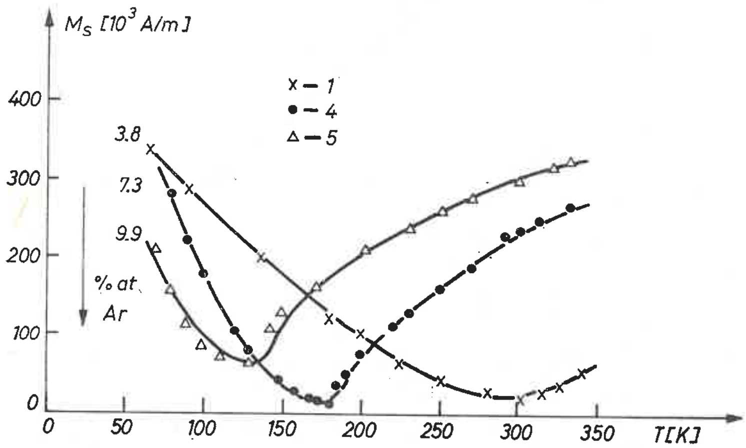

Fig. 3. Saturation magnetisation, M_s, vs temperature, T

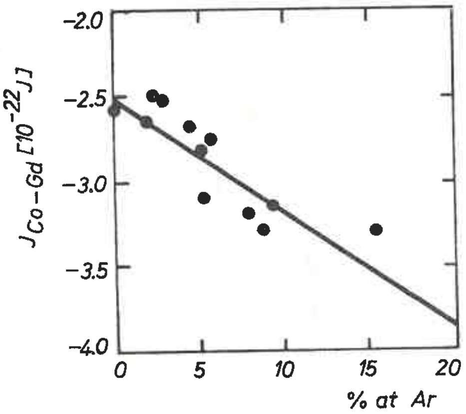

Fig. 4. Exchange integral, J_{Co-Gd} vs Ar concentration [6]

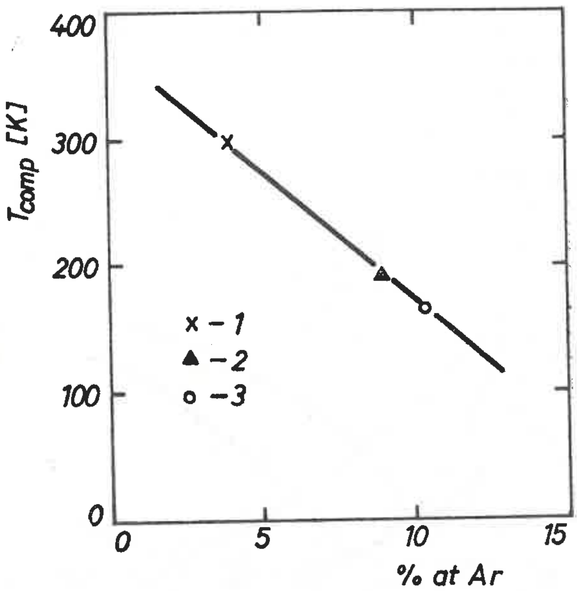

Fig. 5. Temperature compensation, T_{comp} vs Ar concentration

TABLE I

Sample No.	Concentration at. %			Compensation temperature T_{comp} [K]	Resistivity ϱ [10^{-6} Ωm]	TCR [10^{-4} K^{-1}]
	Gd_{1-x}	Co_x	Ar_y			
1	22.8	77.2	3.8	301	2.22	0
2	23.0	77.0	9.0	195	3.63	−1.97
3	22.9	77.1	10.3	170	4.80	−3.78
4	22.3	77.7	7.3	193	3.59	−2.28
5	23.5	76.5	9.9	156	5.02	−2.69

Note: The values, ϱ, are for room temperature, TCR's were measured for a temperature range from 150 to 350 K.

4. Electrical properties

We observed a negative temperature coefficient on the resistance (TCR) between 120 K and 400 K (Fig. 6). Above 400 K the resistivity of ϱ has a positive slope and increases with temperature. This also indicates that oxidation of Gd occurs. The high resistivity of ϱ and the negative TCR in amorphous films can be explained based on the same for-

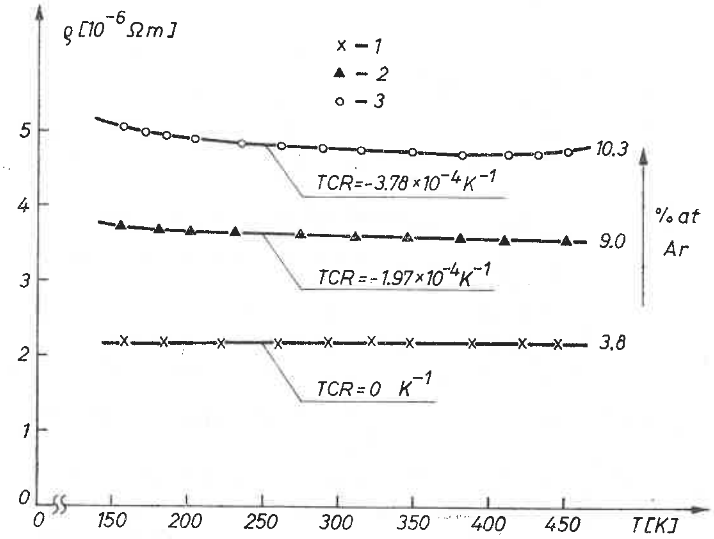

Fig. 6. Resistivity, ϱ, vs temperature, T

malism which was used to calculate the resistivity in liquid transition metals by Nagel [9]. On the other hand, electron microscope and diffraction investigations [10–12] showed that some voids, surface roughness, compositional inhomogeneities, oxide complexes and pores exist in Gd–Co films. The density of these inhomogeneities in microstructure increases

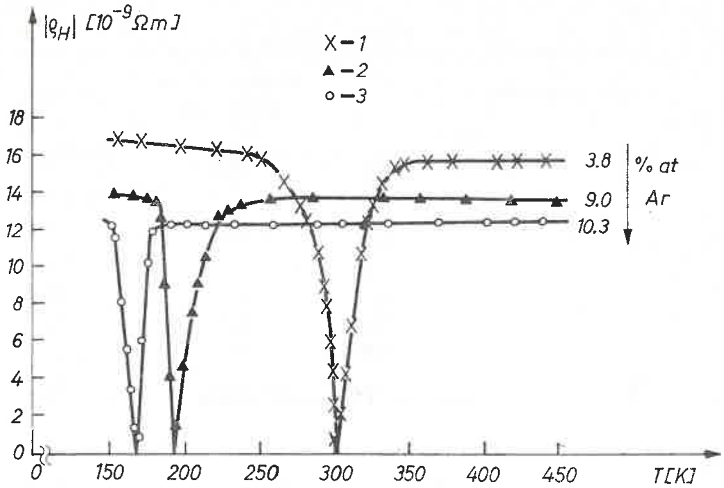

Fig. 7. Modulus of Hall resistivity $|\varrho_H|$ vs temperature, T

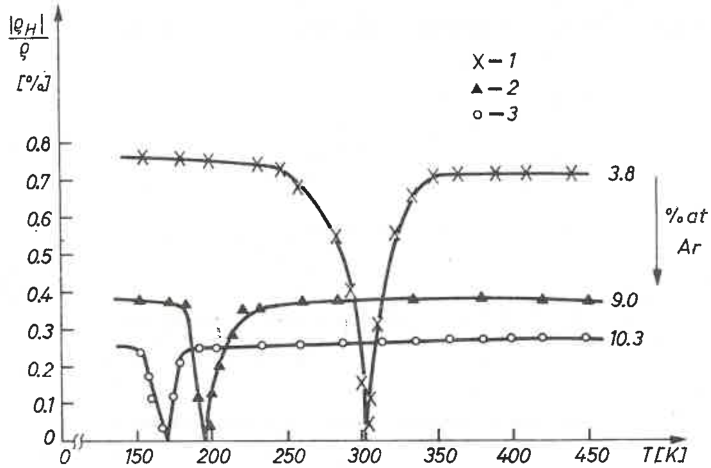

Fig. 8. Modulus of normalized Hall resistivity $|\varrho_H|/\varrho$ vs temperature, T

with an increasing bias voltage. We assume that these inhomogeneities have a fundamental role in the electron scattering processes in Gd-Co films.

The extraordinary Hall resistivity, ϱ_H, decreases slightly with an increase in Ar concentration. This is caused by a decrease in the magnetic moments of the Gd sublattice (Fig. 7). Again, the $|\varrho_H|/\varrho$ ratio depends on the amount of Ar (Fig. 8). With an increase in Ar concentration the resistivity, ϱ, strongly increases (Table I) so that the ratio $|\varrho_H|/\varrho$ is smaller [4].

We conclude from our studies that amorphous thin films with small amount of Ar have both a small H_c and a large $|\varrho_H|/\varrho$.

5. *Devices*

The films can be used as detectors of changes in stray fields arising from movements of the domain structure [13] and also as detectors of weak external magnetic fields [14]. For this purpose we require films with a narrow rectangular Hall loop (small H_c) and a large $|\varrho_H|/\varrho$ ratio. Values having the ratio of approximately 0.01 are large enough to be detectors with a sensitivity competitive to semiconductors of the Hall type [14].

The authors wish to express their thanks to Drs L. Maksymowicz and A. Maksymowicz for many helpful discussions, to Dr Z. Obuszko for utilizing the Faraday balance, to H. Jankowski, eng., for sample preparation, and to Mr. A. Janas for the electron microprobe and X-ray analyses.

REFERENCES

[1] H. Jankowski, L. Kozłowski, J. Wenda, W. Gawior, N. Lewandowska, Phys. of Magnetics, Conf. Proc., June 27–30, 1978, Poznań, Poland.
[2] L. Maksymowicz, H. Jankowski, J. Wenda, The 9th International Colloquium on Magnetic Films and Surfaces, August 28–31, 1979, Poznań, Poland.
[3] T. Stobiecki, H. Jankowski, J. Wenda, *Thin Solid Films* **51**, 197 (1978).
[4] T. Groń, T. Stobiecki, The 9th International Colloquium on Magnetic Films and Surfaces, August 28–31, 1979, Poznań, Poland.
[5] R. J. Kobilska, A. Gangulee, D. E. Cox, C. H. Bajorek, *IEEE Trans. Magn.* **13**, 1767 (1977).
[6] A. Gangulee, R. J. Kobilska, *J. Appl. Phys.* **49**, 4169 (1978).
[7] T. Stobiecki, H. Jankowski, Z. Obuszko, T. Groń, Phys. of Magnetics, Conf. Proc., June 27–30, 1978, Poznań, Poland.
[8] H. R. Muller, E. Jager, M. Bitterlich, *Phys. Status Solidi* (b) **80**, K85 (1977).
[9] S. R. Nagel, *Phys. Rev.* **B16**, 1694 (1977).
[10] S. R. Herd, *Phys. Status Solidi* (a) **44**, 363 (1977).
[11] S. R. Herd, *J. Appl. Phys.* **49**, 1749 (1978).
[12] J. F. Graczyk, *J. Appl. Phys.* **49**, 1738 (1978).
[13] G. S. Almasi, G. E. Keefe, Y. S. Lin, D. A. Thompson, *J. Appl. Phys.* **42**, 1268 (1971).
[14] T. R. McGuire, R. J. Gambino, R. C. Taylor, *J. Appl. Phys.* **48**, 2965 (1977).